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SUMMARY OF CRITICAL-MASS CONFIGURATIONS, MATERIAL CONCENTRATIONS, AND CONTROL-ROD WORTHS FOR ZPR-9 ZONED FAST CRITICAL ASSEMBLIES 11-25

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Applied Physics Division

March 1971

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

A detailed review has been made of ZPR-9 Assemblies 11-25 of the "as-built" reactor properties including regional radii, critical masses, regional atomic concentrations, and measured control-rod worths. This review was made in order to process and compile the data in a consistent manner. Not included in the review are the rocket critical-assembly program prior to Assembly 11 and the FTR critical studies succeeding Assembly 25.

INTRODUCTION

ZPR-9 Assemblies 11-25 were designed for purposes other than to establish clean configurations. Assemblies 11 and 12[1] were uranium carbide cores designed for measurements of Doppler coefficients and reactivity worths and to test the usefulness of measurements in a small zone for predicting the performance of a full-sized reactor. Assemblies 13-17[2] provided a series of zoned cores with progressively softer spectra designed primarily to investigate the Doppler effect of ^{235}U. Assemblies 19, 21, and 22[3,4] were uranium oxide cores used to develop experimental methods for checking the adequacy of zoned core designs and to test the sensitivity of the zoned core spectrum to small changes in core composition and size. Measurements of ^{239}Pu and ^{235}U capture-to-fission ratio (alpha) were made on Assembly 24.[4,5] The neutron energy spectrum in Assembly 24 emphasized the region of largest uncertainty in the ^{239}Pu alpha (i.e., 1 to 10 keV). Assembly 25,[6,7] with a spectrum significantly harder than that of Assembly 24, was aimed at providing integral data relevant to the resolution of some of the cross-section uncertainties in ^{238}U and ^{239}Pu. Assemblies 24 and 25 both contained null (i.e., $k_\infty = 1$) central zones. The data on Assemblies 18 and 23 were not included, since they were identical to Assemblies 12 and 19, respectively. An assembly designated as number 20 was planned as part of the oxide zone series, but was never constructed.

In each assembly, the "as-built" loading which came closest to a clean configuration was chosen as a reference. The values from this reference loading are listed in the tables in this report and should be considered as the reference values for the assembly, superseding all previous values.

TREATMENT OF DATA

Each of the 12 assemblies reviewed was treated with a consistent set of considerations in order to form a common basis. Since this set of considerations, described below, may not have been used in preparing previous reports, comparison of tabulated values between this report and other reports may show minor differences.

Regional Dimensions

Equivalent cylindrical regional radii were determined, based on the number of matrix-tube positions per region. Outside dimensions of a stainless steel matrix tube gave a cross-sectional area of 30.464 cm^2. Where empty matrix tubes existed in a region, or where a void occurred due to a partially inserted control rod, the cross-sectional area of each void was included in determining the radius. For convenience of loading, certain assemblies had one additional driver drawer in either the stationary or the movable half. The average number of matrix positions were used in the computation of the radius. Figures 1-24 show radial assembly loading patterns for each half of the 12 assemblies. The figures are oriented as one would view each half from a position between the halves.

Drawer loading patterns for each assembly are shown in Figs. 25-35. Stationary half patterns are shown, except as indicated. The patterns are referenced to a view facing the front of the drawer. Usually mirror images of the stationary half patterns prevailed in the movable half so that continuous columns of material existed through both halves.

Elevations of each assembly are shown in Figs. 36-44. All assemblies used 18-in. (45.72-cm) half heights of the test zone, buffer, and driver regions. Axial dimensions in these figures include the thickness of the ends of the stainless steel drawers, 0.032 in. (0.08 cm), and of the stainless steel springs located at the back of each drawer.

Critical Mass

For each reference configuration, the critical mass has been corrected for the partially inserted fuel-bearing control rods. Only that fraction of the partially inserted rod that was actually in the reactor was included in the critical mass.

Corrections have also been included for the presence of fission counters. In Assembly 25, four matrix-tube positions are designated [D] (Figs. 23 and 24). Fission counters in these drawers were placed 6 in. (15.24 cm) from the front of the drawer. They occupied a space 2 x 2 x 2 in. and required an additional 1/2-in. void column behind the counter to facilitate the signal cable and gas line. The axial oscillator, also in Assembly 25, was treated as two regular test-zone drawers.

Tabulated critical masses include all the ^{235}U (including that in the depleted uranium and in the U_3O_8) in the test zone, buffer, and driver regions.

Atomic Concentrations

Regional concentrations include the effect of any partially inserted control rod; that is, the partial void from the control rod is averaged throughout the region. Empty matrix-tube positions within any region served to reduce the number densities of that region.

Composition for the Type 304 stainless steel used in drawers, sodium cladding, matrix tubes, and plates was taken as: iron 71.5%, chromium 19%, and nickel 9.5%. The steel reflector, referred to in all assemblies except Assembly 25, is composed of blocks of AISI C1018 cold-finished steel loaded into regular stainless steel drawers. Type C1018 steel has the composition: iron 99.5%, carbon 0.17%, manganese 0.71%, phosphorus 0.01%, sulfur 0.02%, and chromium 0.03%, where only the iron content has been considered. Nickel plates and stainless steel plates were loaded into regular stainless steel drawers for the nickel and stainless steel reflectors of Assembly 25. Radial and axial depleted-uranium reflectors were normally made up of large depleted-uranium blocks inserted directly into matrix positions without stainless steel drawers.

Atom densities are tabulated in Tables I-XII.

Control-rod Worths

Measured control-rod worths are listed in Table XIII. Assembly 15 was constructed only briefly to obtain the necessary critical-mass information to load Assemblies 16 and 17, and no control-rod worths were measured. The boron blade in the boron control rod shown in Assemblies 11, 12, 13, 19, 24, and 25 had exterior dimensions of 1 x 5 x 61 cm and consisted nominally of 230 g of enriched boron powder (175 g ^{10}B) distributed within the stainless steel cladding of 0.032-in. (0.08-cm) thickness. In Assembly 25, the boron control rod (located in the stainless steel reflector region) was not used for reactor measurements. Total travel distance of the boron control rods was 30 in. (76.2 cm). Fuel-bearing control rods had a total stroke of 24 in. (60.96 cm).

Fine autorods contained either a tapered boral spear or a tapered polyethylene spear. The boral spear tapered from $1\frac{1}{4}$ in. to 1/4 in. in a length of 65 in. (165.1 cm) and was clad in 0.032-in. (0.08-cm) stainless steel. For the polyethylene spear, the taper was from 2 to 1/4 in., in a total distance of 7 ft 6 in. (228.6 cm). Both the stainless steel-clad boral and the polyethylene spear were approximately 1/4 in. thick. In Assembly 25, the only assembly to use the polyethylene spear, the worth of the fine autorod in a 6-in. (15.24-cm) stroke was approximately 0.01% $\Delta k/k$.

The coarse autorod in the movable half of Assembly 16 (Fig. 12) had a measured worth of 0.09% $\Delta k/k$.

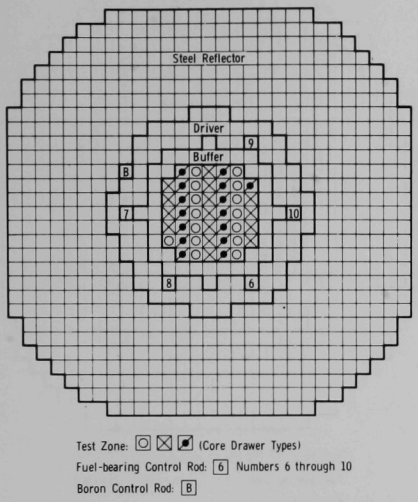


Fig. 1. Radial Assembly Loading Pattern: ZPR-9 Assembly 11, Loading 15, Stationary Half

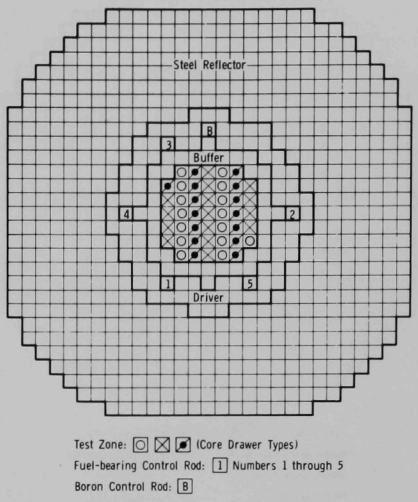


Fig. 2. Radial Assembly Loading Pattern: ZPR-9 Assembly 11, Loading 15, Movable Half

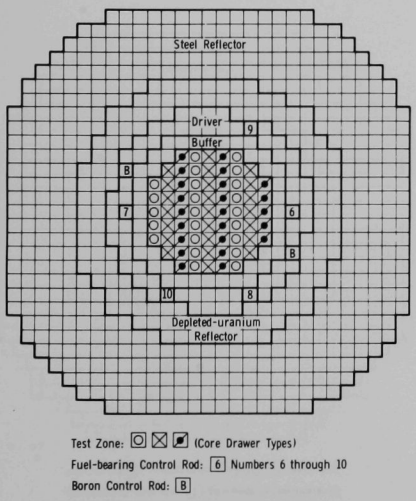


Fig. 3. Radial Assembly Loading Pattern: ZPR-9 Assembly 12, Loading 10, Stationary Half

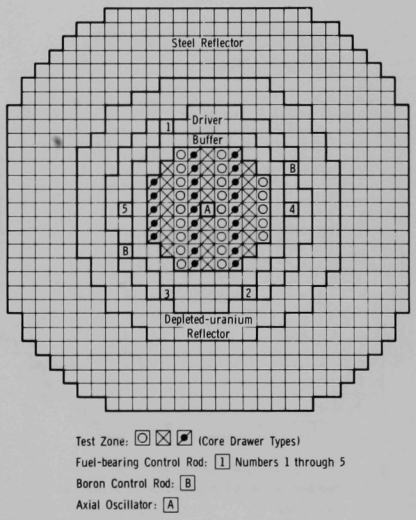


Fig. 4. Radial Assembly Loading Pattern: ZPR-9 Assembly 12, Loading 10, Movable Half

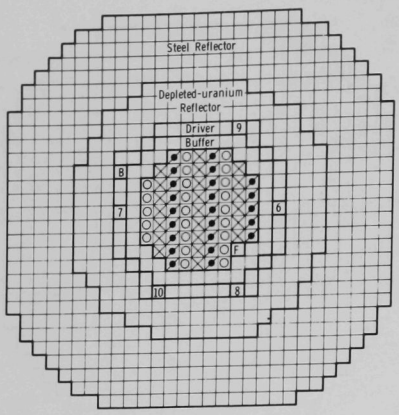


Fig. 5. Radial Assembly Loading Pattern: ZPR-9 Assembly 13, Loading 9, Stationary Half

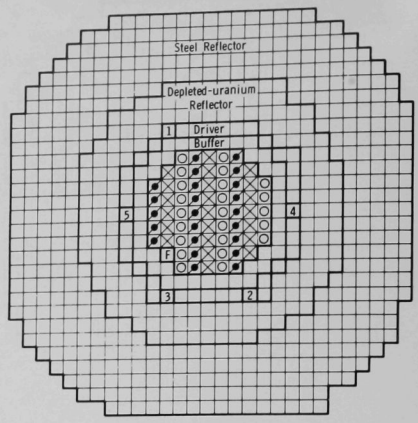


Fig. 6. Radial Assembly Loading Pattern: ZPR-9 Assembly 13, Loading 9, Movable Half

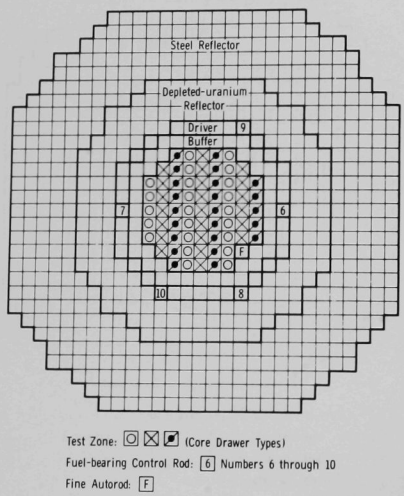


Fig. 7. Radial Assembly Loading Pattern: ZPR-9 Assembly 14, Loading 4, Stationary Half

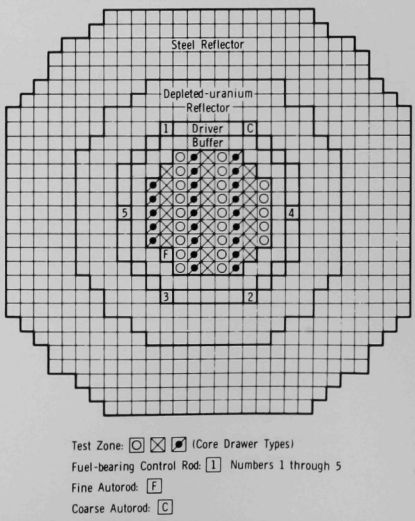


Fig. 8. Radial Assembly Loading Pattern: ZPR-9 Assembly 14, Loading 4, Movable Half

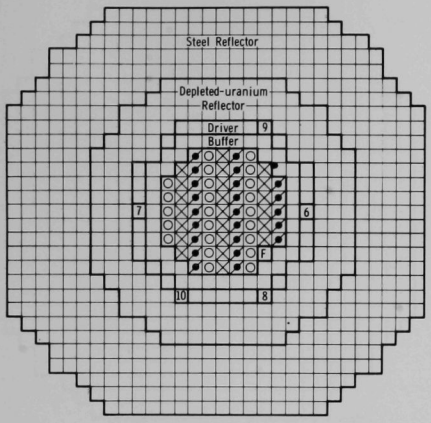


Fig. 9. Radial Assembly Loading Pattern: ZPR-9 Assembly 15, Loading 4, Stationary Half

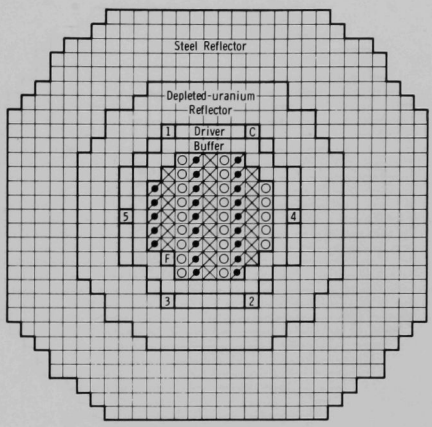


Fig. 10. Radial Assembly Loading Pattern: ZPR-9 Assembly 15, Loading 4, Movable Half

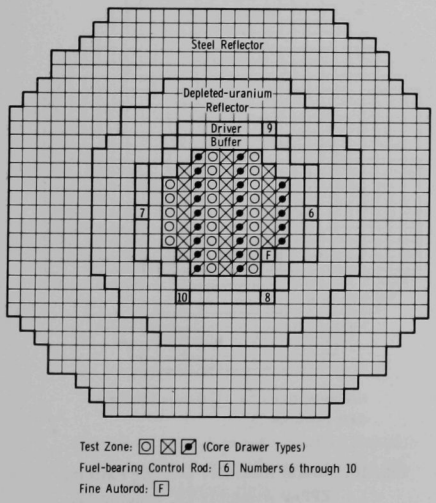


Fig. 11. Radial Assembly Loading Pattern: ZPR-9 Assembly 16, Loading 2, Stationary Half

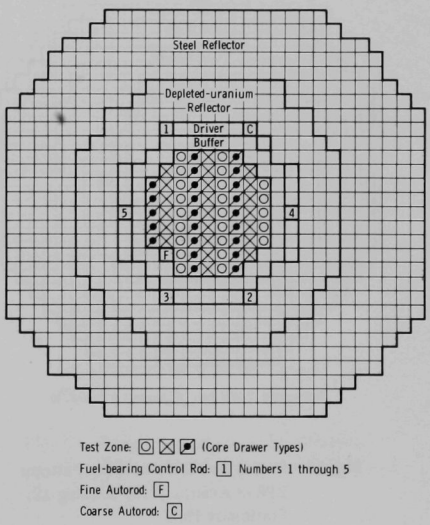


Fig. 12. Radial Assembly Loading Pattern: ZPR-9 Assembly 16, Loading 2, Movable Half

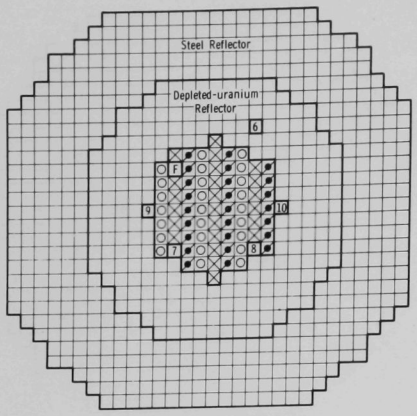


Fig. 13. Radial Assembly Loading Pattern: ZPR-9 Assembly 17, Loading 61, Stationary Half

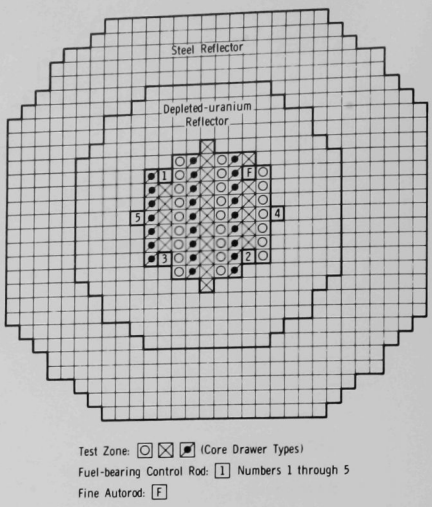


Fig. 14. Radial Assembly Loading Pattern: ZPR-9 Assembly 17, Loading 61, Movable Half

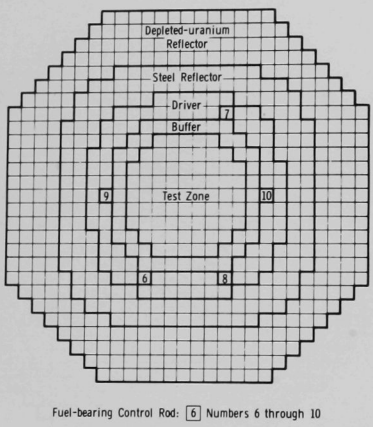


Fig. 15. Radial Assembly Loading Pattern: ZPR-9 Assembly 19, Loading 12, Stationary Half

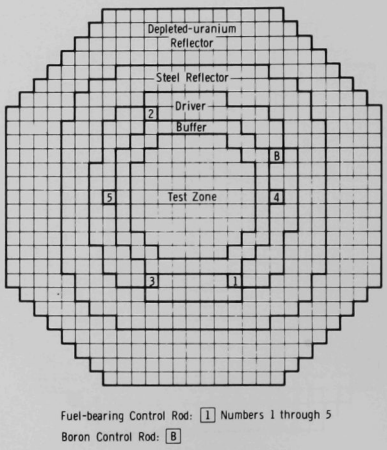
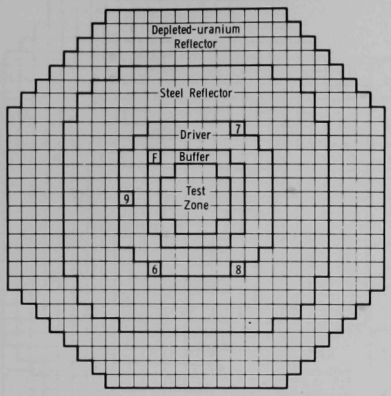
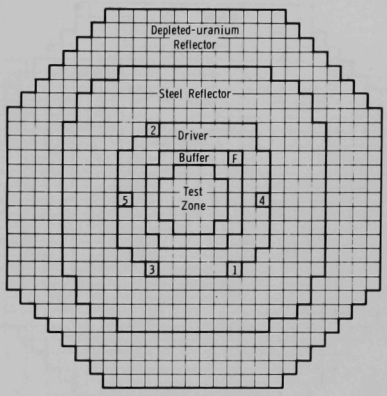


Fig. 16. Radial Assembly Loading Pattern: ZPR-9 Assembly 19, Loading 12, Movable Half



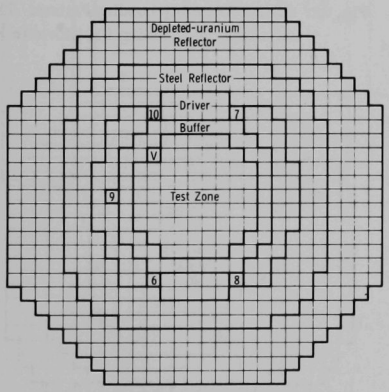
Fuel-bearing Control Rod: 6 Numbers 6 through 9
Fine Autorod: F

Fig. 17. Radial Assembly Loading Pattern: ZPR-9 Assembly 21, Loading 13, Stationary Half



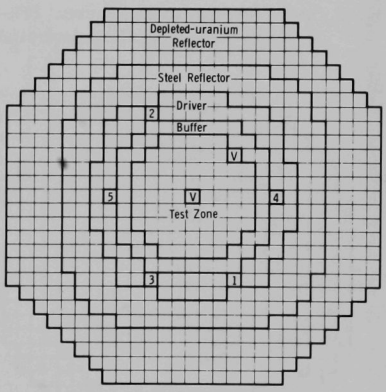
Fuel-bearing Control Rod: 1 Numbers 1 through 5
Fine Autorod: F

Fig. 18. Radial Assembly Loading Pattern: ZPR-9 Assembly 21, Loading 13, Movable Half



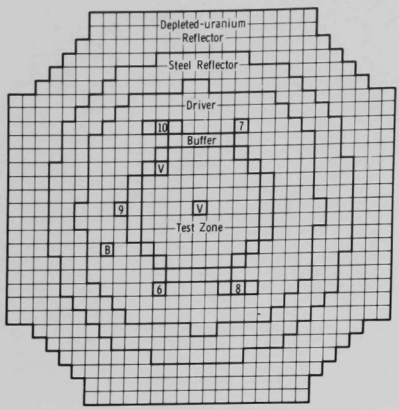
Fuel-bearing Control Rod: 6 Numbers 6 through 10
Void: V

Fig. 19. Radial Assembly Loading Pattern: ZPR-9 Assembly 22, Loading 10, Stationary Half



Fuel-bearing Control Rod: 1 Numbers 1 through 5
Void: V

Fig. 20. Radial Assembly Loading Pattern: ZPR-9 Assembly 22, Loading 10, Movable Half



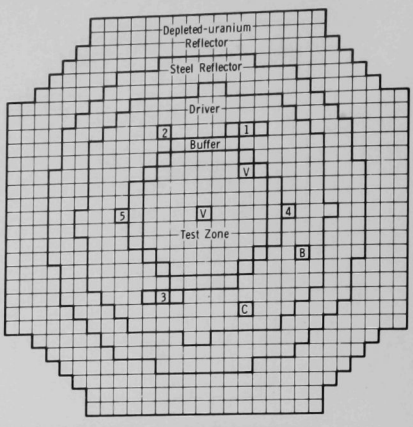
Fuel-bearing Control Rod and Adjacent Drawers: [8] Numbers 8 and 10 (three columns of fuel in rod, no fuel in adjacent drawers)

Fuel-bearing Control Rod: [6] Numbers 6, 7, and 9 (one column of fuel)

Boron Control Rod: [B]

Void: [V]

Fig. 21. Radial Assembly Loading Pattern: ZPR-9 Assembly 24, Loading 21, Stationary Half



Fuel-bearing Control Rod and Adjacent Drawers: [1] Numbers 1 and 3 (three columns of fuel in rod, no fuel in adjacent drawers)

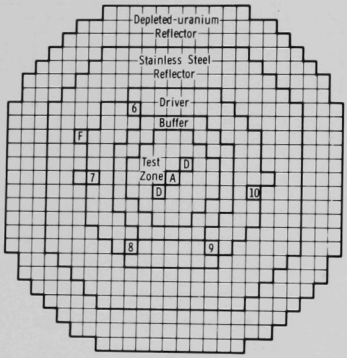
Fuel-bearing Control Rod: [2] Numbers 2, 4, and 5 (one column of fuel)

Boron Control Rod: [B]

Coarse Autorod: [C]

Void: [V]

Fig. 22. Radial Assembly Loading Pattern: ZPR-9 Assembly 24, Loading 21, Movable Half



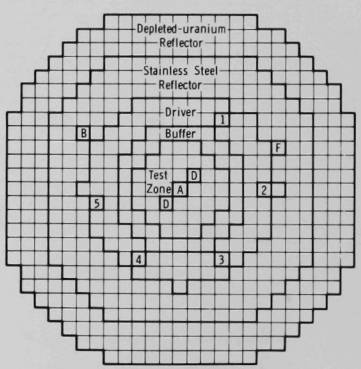
Fuel-bearing Control Rod: [6] Numbers 6 through 10

Fine Autorod: [F]

Axial Oscillator: [A]

Fission Detector: [D]

Fig. 23. Radial Assembly Loading Pattern: ZPR-9 Assembly 25, Loading 24, Stationary Half



Fuel-bearing Control Rod: [1] Numbers 1 through 5

Fine Autorod: [F]

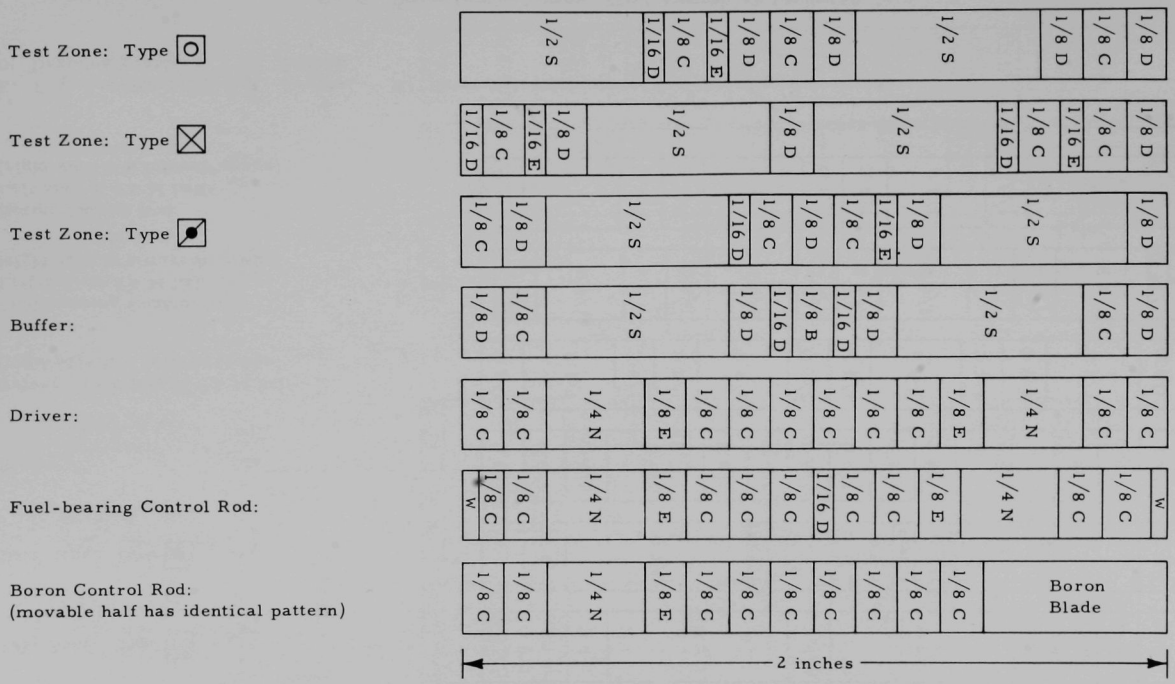
Axial Oscillator: [A]

Fission Detector: [D]

Boron Control Rod: [B]

Fig. 24. Radial Assembly Loading Pattern: ZPR-9 Assembly 25, Loading 24, Movable Half

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



E: Enriched Uranium
D: Depleted Uranium
C: Carbon
B: $B_4{}^{nat}C$
S: Sodium
N: Nickel
W: Extra wall thickness on fuel-bearing control rods.

Fig. 25. Drawer Loading Patterns: ZPR-9 Assembly 11, Loading 15

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.

Test Zone: Type ⊙

Test Zone: Type ⊠

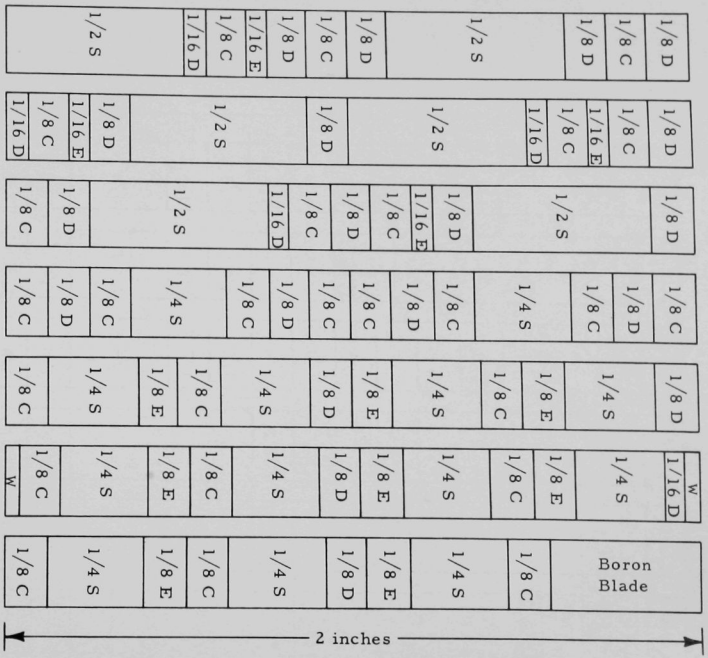
Test Zone: Type ◪

Buffer:

Driver: Left side of S & M half--
(right side is a mirror image)

Fuel-bearing Control Rod:
Left side of S & M half--
(right side is a mirror image)

Boron Control Rod:
Left side of S & M half--
(right side is a mirror image)



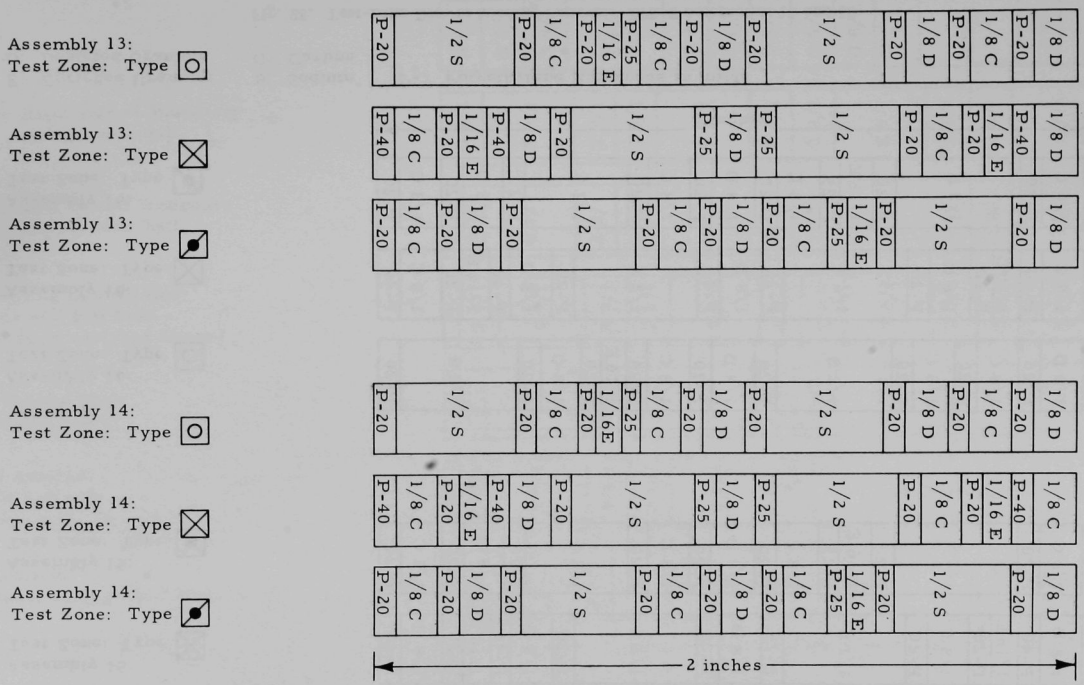
E: Enriched Uranium
D: Depleted Uranium

C: Carbon
S: Sodium

W: Extra wall thickness on fuel-bearing control rods.

Fig. 26. Drawer Loading Patterns: ZPR-9 Assembly 12, Loading 10

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



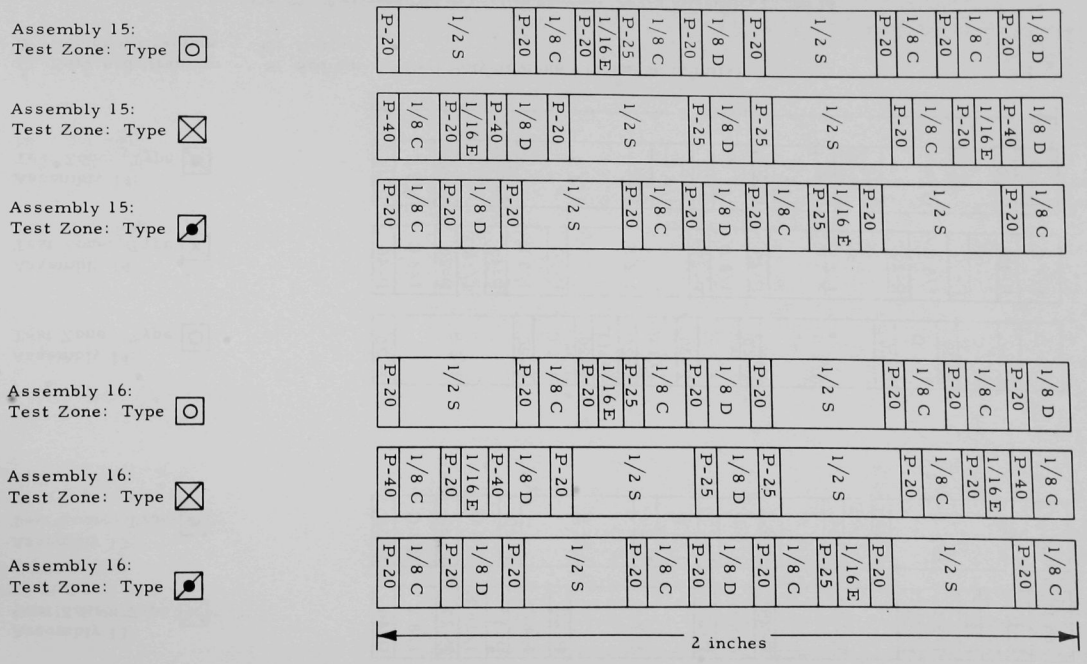
E: Enriched Uranium
D: Depleted Uranium

S: Sodium
C: Carbon

P-: Polyethylene (thickness in mils)

Fig. 27. Test-zone Drawer Loading Patterns: ZPR-9 Assemblies 13 and 14

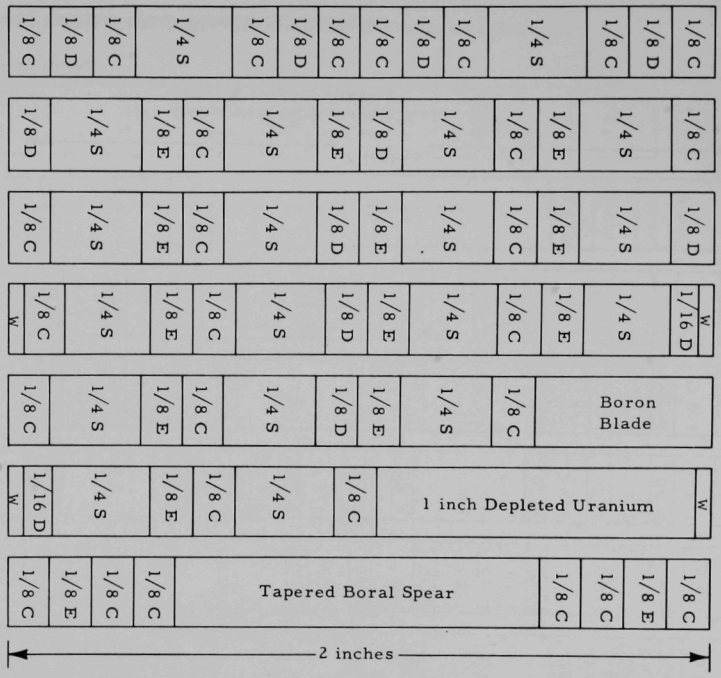
Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



E: Enriched Uranium S: Sodium P-: Polyethylene (thickness in mils)
D: Depleted Uranium C: Carbon

Fig. 28. Test-zone Drawer Loading Patterns: ZPR-9 Assemblies 15 and 16

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



E: Enriched Uranium
D: Depleted Uranium
C: Carbon
S : Sodium
W: Extra wall thickness on fuel-bearing control rods.

Fig. 29. Drawer Loading Patterns: ZPR-9 Assemblies 13-16

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.

Test Zone: Type ⊙

Test Zone: Type ⊠

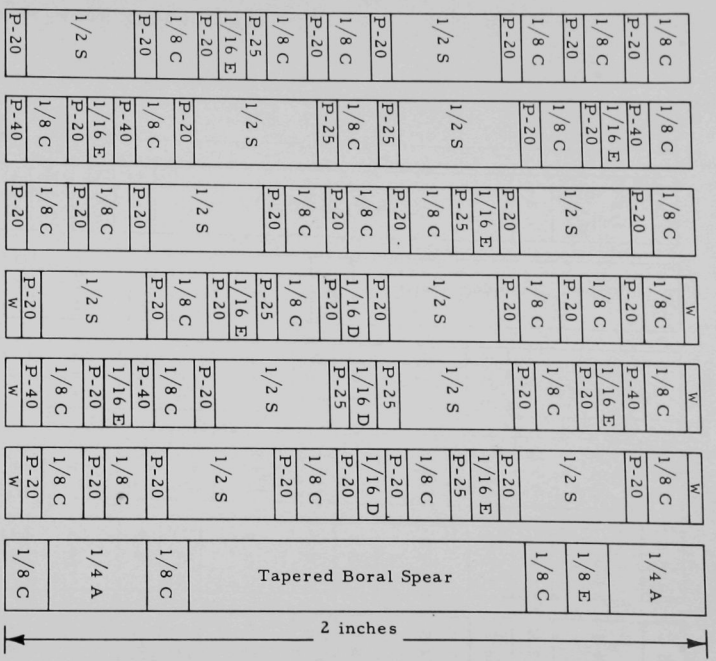
Test Zone: Type ◪

Fuel-bearing Control Rod: Number 10
(mirror image, number 5)

Fuel-bearing Control Rod: Numbers 7, 8
(mirror image, numbers 1, 2, & 3)

Fuel-bearing Control Rod: Number 9
(mirror image, number 4)

Fine Autorod:
(continuous through both halves)



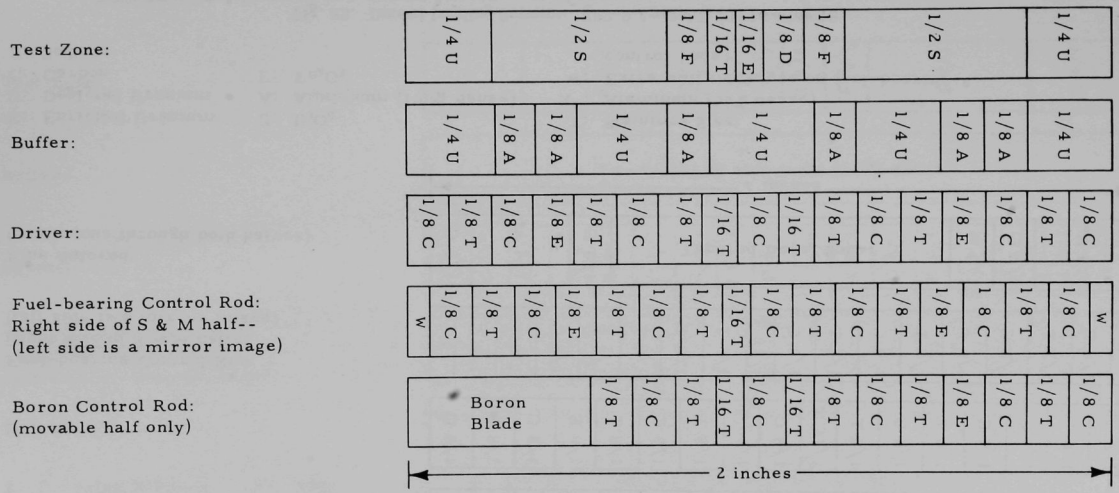
E: Enriched Uranium
D: Depleted Uranium
C: Carbon

S: Sodium
A: Aluminum (63% dense)
P-: Polyethylene (thickness in mils)

W: Extra wall thickness on fuel-bearing control rods.

Fig. 30. Drawer Loading Patterns: ZPR-9 Assembly 17, Loading 61

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



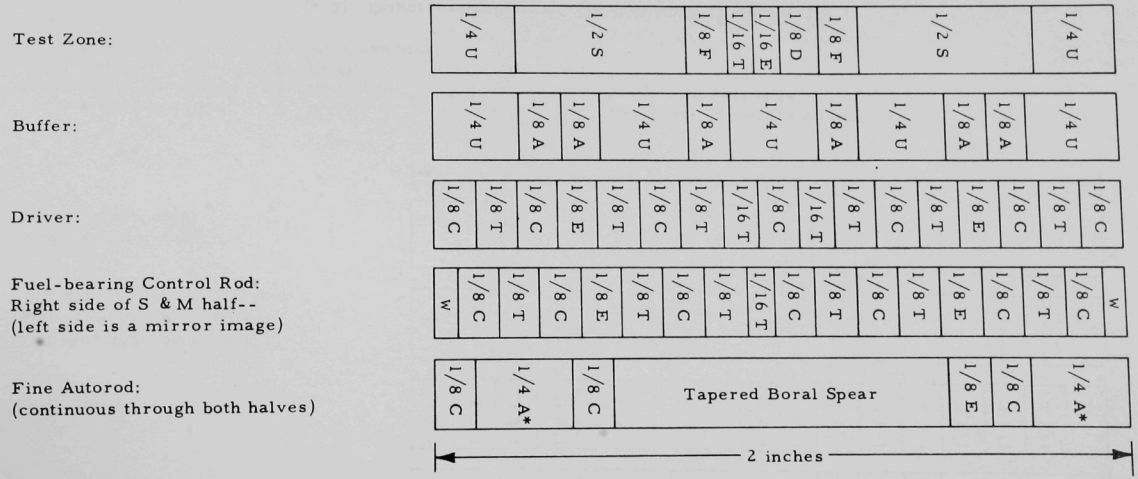
E: Enriched Uranium
D: Depleted Uranium
C: Carbon
S: Sodium

U: U_3O_8
A: Aluminum (100% dense)
F: Fe_2O_3
T: Stainless Steel

W: Extra wall thickness on fuel-bearing control rods

Fig. 31. Drawer Loading Patterns: ZPR-9 Assembly 19, Loading 12

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



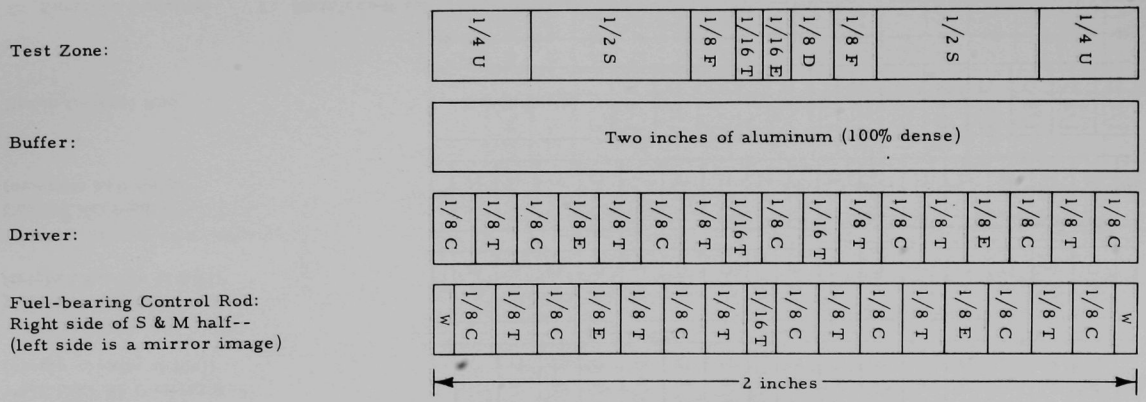
E: Enriched Uranium
D: Depleted Uranium
C: Carbon
S: Sodium

U: U_3O_8
A: Aluminum (100% dense)
F: Fe_2O_3

T: Stainless Steel
A*: Aluminum (56% dense)
W: Extra wall thickness on fuel-bearing control rods

Fig. 32. Drawer Loading Patterns: ZPR-9 Assembly 21, Loading 13

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



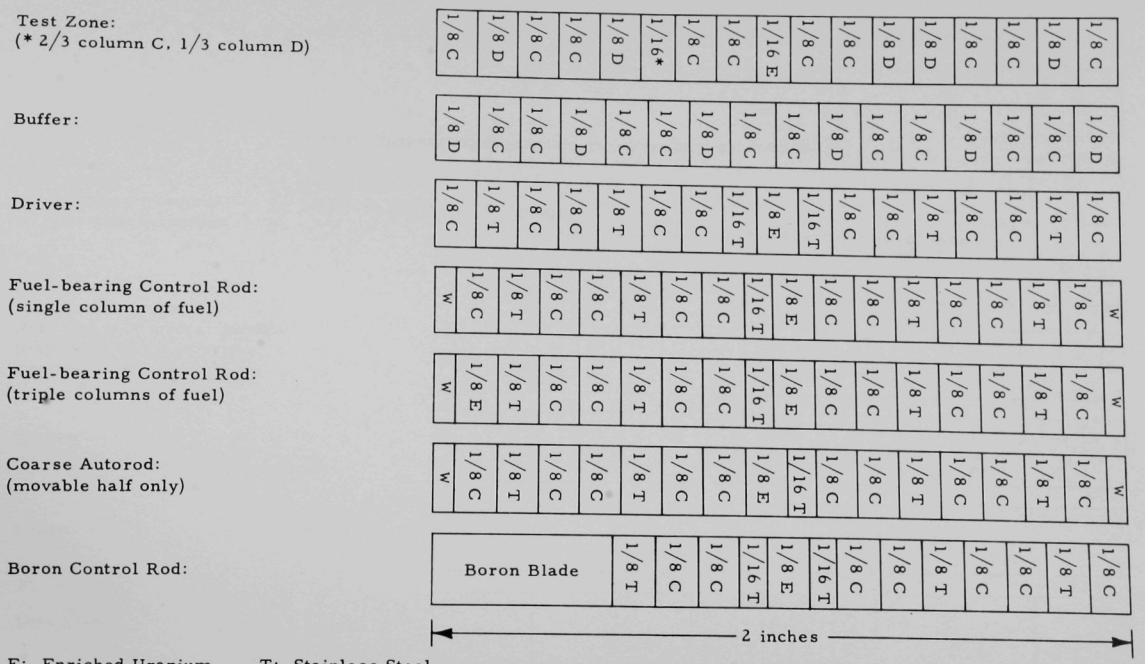
E: Enriched Uranium
D: Depleted Uranium
C: Carbon

U: U_3O_8
T: Stainless Steel
F: Fe_2O_3

W: Extra wall thickness on fuel-bearing control rods
S: Sodium

Fig. 33. Drawer Loading Patterns: ZPR-9 Assembly 22, Loading 10

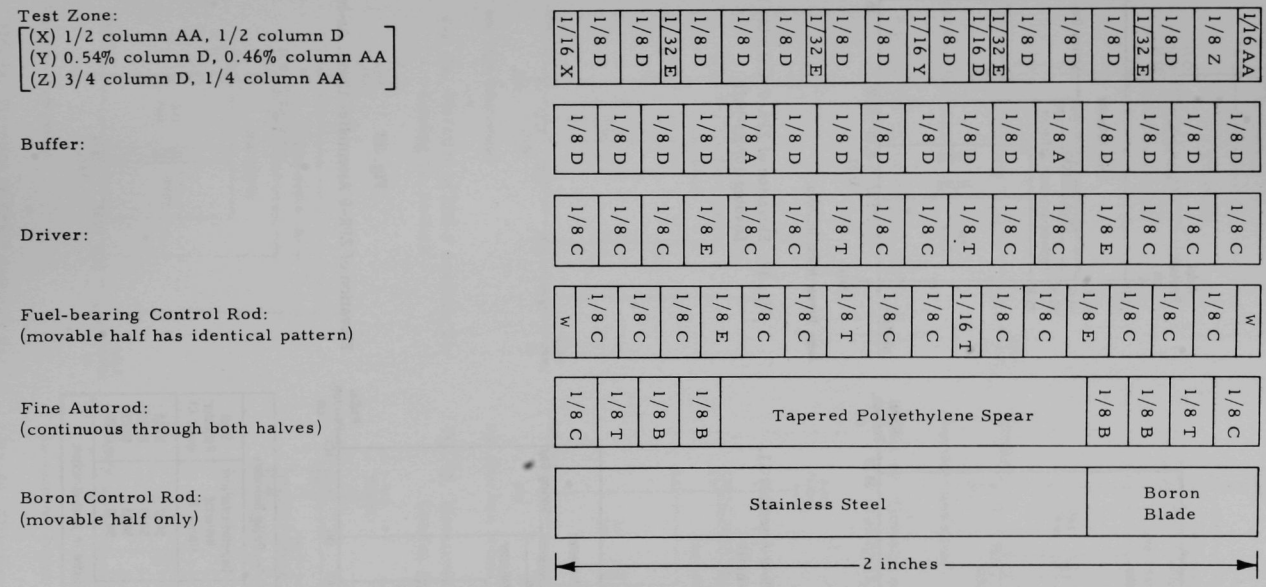
Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.



E: Enriched Uranium
D: Depleted Uranium
C: Carbon
T: Stainless Steel
W: Extra wall thickness on fuel-bearing control rods
*: 2/3 column C, 1/3 column D

Fig. 34. Drawer Loading Patterns: ZPR-9 Assembly 24, Loading 21

Stationary half patterns are shown; movable half patterns are mirror images, except as indicated.

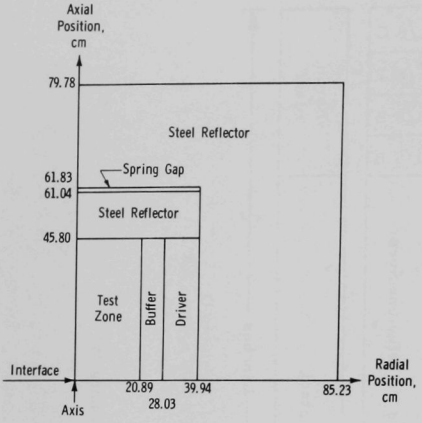


E: Enriched Uranium
D: Depleted Uranium
A: Aluminum (100% dense)
AA: Aluminum (45% dense)

T: Stainless Steel
B: $B_4{}^{nat}C$
W: Extra wall thickness on fuel-bearing control rods

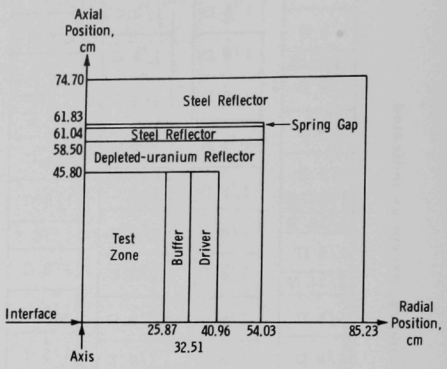
X: 1/2 column AA, 1/2 column D
Y: 0.54% column D, 0.46% column AA
Z: 3/4 column D, 1/4 column AA

Fig. 35. Drawer Loading Patterns: ZPR-9 Assembly 25, Loading 24



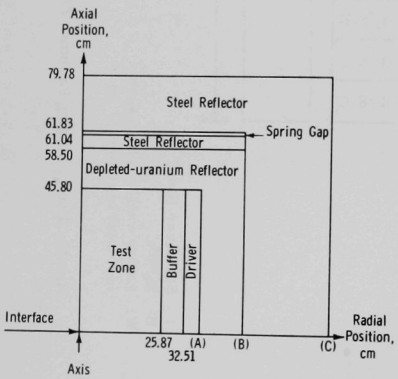
Note: Drawer fronts included.

Fig. 36. Elevation of ZPR-9 Assembly 11, Loading 15, As-built



Note: Drawer fronts included.

Fig. 37. Elevation of ZPR-9 Assembly 12, Loading 10, As-built

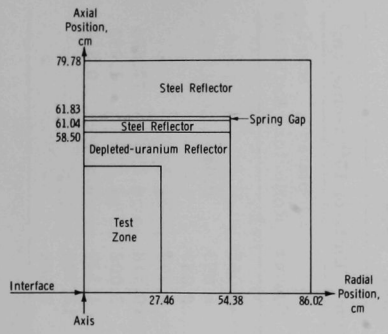


Assembly	Loading	Outer Radial Boundary		
		Driver (point A)	Depleted-uranium Reflector (point B)	Steel Reflector (point C)
13	9	37.85	54.07	85.14
14	4	37.35	54.43	84.40
15	4	36.97	54.43	86.05
16	2	36.62	54.38	86.05

Note: Drawer fronts included in axial direction.

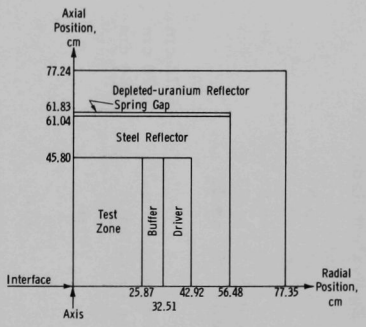
Fig. 38

Elevation of ZPR-9 Assemblies 13-16, As-built



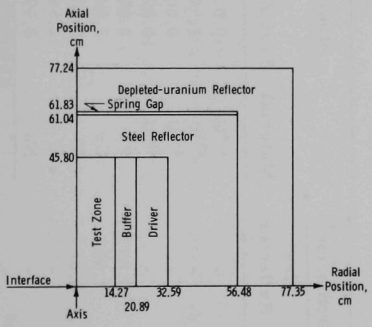
Note: Drawer fronts included.

Fig. 39. Elevation of ZPR-9 Assembly 17, Loading 61, As-built



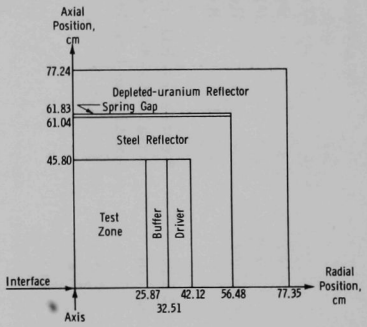
Note: Drawer fronts included.

Fig. 40. Elevation of ZPR-9 Assembly 19, Loading 12, As-built



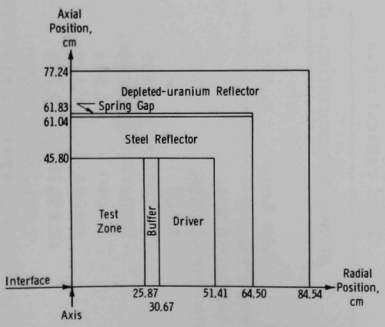
Note: Drawer fronts included.

Fig. 41. Elevation of ZPR-9 Assembly 21, Loading 13, As-built



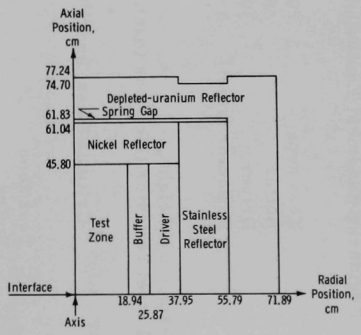
Note: Drawer fronts included.

Fig. 42. Elevation of ZPR-9 Assembly 22, Loading 10, As-built



Note: Drawer fronts included.

Fig. 43. Elevation of ZPR-9 Assembly 24, Loading 21, As-built



Note: Drawer fronts included.

Fig. 44. Elevation of ZPR-9 Assembly 25, Loading 24, As-built

TABLE I. ZPR-9 Assembly 11, Loading 15, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	20.89
Buffer	28.03
Driver	39.94
Reflector (steel)	85.23

Test-zone half height	45.72 cm
Axial steel reflector thickness (each half)	33.02 cm

Critical Mass, kg (^{235}U)

Test zone	76
Buffer	1
Driver	403
Total critical mass	480.1

	Atomic Concentrations, Units of 10^{21} atoms/cm^3			
Material	Test Zone	Buffer	Driver	Steel Reflector
^{234}U	0.015	-	0.044	-
^{235}U	1.548	0.026	4.443	-
^{236}U	0.007	-	0.021	-
^{238}U	10.610	12.145	0.320	-
Fe	8.904	8.904	6.839	77.893
Cr	2.541	2.541	1.952	1.952
Ni	1.125	1.125	18.540	0.864
C	12.856	9.354	41.874	-
Na	9.001	9.001	-	-
B(nat.)	-	3.023	-	-

TABLE II. ZPR-9 Assembly 12, Loading 10, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	32.51
Driver	40.96
Reflector (depleted)	54.03
Reflector (steel)	85.23

Test-zone half height	45.72 cm
Axial depleted reflector thickness (each half)	12.70 cm
Axial steel reflector thickness (each half)	15.24 cm

Critical Mass, kg (^{235}U)

Test zone	116
Buffer	1
Driver	463
Total critical mass	579.7

	Atomic Concentrations, Units of 10^{21} atoms/cm^3				
Material	Test Zone	Buffer	Driver	Depleted Reflector	Steel Reflector
^{234}U	0.015	-	0.065	-	-
^{235}U	1.543	0.020	6.653	0.085	-
^{236}U	0.007	-	0.031	-	-
^{238}U	10.628	9.704	4.999	40.133	-
Fe	8.904	8.726	10.518	4.256	77.893
Cr	2.541	2.491	3.002	1.125	1.952
Ni	1.125	1.103	1.329	0.538	0.864
C	12.848	34.303	12.780	-	-
Na	8.998	3.807	7.505	-	-

TABLE III. ZPR-9 Assembly 13, Loading 9, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	32.51
Driver	37.85
Reflector (depleted)	54.07
Reflector (steel)	85.14

Test-zone half height	45.72 cm
Axial depleted reflector thickness (each half)	12.70 cm
Axial steel reflector thickness (each half)	20.32 cm

Critical Mass, kg (^{235}U)

Test zone	115
Buffer	1
Driver	287
Total critical mass	402.8

	Atomic Concentrations, Units of 10^{21} atoms/cm^3				
Material	Test Zone	Buffer	Driver	Depleted Reflector	Steel Reflector
^{234}U	0.015	-	0.065	-	-
^{235}U	1.541	0.020	6.629	0.085	-
^{236}U	0.007	-	0.031	-	-
^{238}U	7.254	9.704	4.983	40.133	-
Fe	8.904	8.726	10.264	4.256	77.893
Cr	2.541	2.491	2.971	1.215	1.952
Ni	1.125	1.103	1.316	0.538	0.864
C	15.197	34.303	12.755	-	-
Na	8.871	3.807	7.450	-	-
H	6.645	-	-	-	-

TABLE IV. ZPR-9 Assembly 14, Loading 4, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	32.51
Driver	37.35
Reflector (depleted)	54.43
Reflector (steel)	84.40

Test-zone half height	45.72 cm
Axial depleted reflector thickness (each half)	12.70 cm
Axial steel reflector thickness (each half)	20.32 cm

Critical Mass, kg (^{235}U)

Test zone	115
Buffer	1
Driver	258
Total critical mass	374.1

	Atomic Concentrations, Units of 10^{21} atoms/cm^3				
Material	Test Zone	Buffer	Driver	Depleted Reflector	Steel Reflector
^{234}U	0.015	-	0.066	-	-
^{235}U	1.539	0.020	6.730	0.085	-
^{236}U	0.007	-	0.032	-	-
^{238}U	6.490	9.704	4.988	40.133	-
Fe	8.904	8.726	10.503	4.256	77.893
Cr	2.541	2.491	2.998	1.215	1.952
Ni	1.125	1.103	1.327	0.538	0.864
C	16.493	34.303	12.826	-	-
Na	8.871	3.807	7.460	-	-
H	6.645	-	-	-	-

TABLE V. ZPR-9 Assembly 15, Loading 4, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	32.51
Driver	36.97
Reflector (depleted)	54.43
Reflector (steel)	86.05

Test-zone half height	45.72 cm
Axial depleted reflector thickness (each half)	12.70 cm
Axial steel reflector thickness (each half)	20.32 cm

Critical Mass, kg (^{235}U)

Test zone	115
Buffer	1
Driver	237
Total critical mass	352.9

	Atomic Concentrations, Units of 10^{21} atoms/cm^3				
Material	Test Zone	Buffer	Driver	Depleted Reflector	Steel Reflector
^{234}U	0.015	-	0.066	-	-
^{235}U	1.537	0.020	6.731	0.085	-
^{236}U	0.007	-	0.032	-	-
^{238}U	5.681	9.704	4.944	40.133	-
Fe	8.904	8.726	10.403	4.256	77.893
Cr	2.541	2.491	2.969	1.215	1.952
Ni	1.125	1.103	1.315	0.538	0.864
C	18.166	34.303	12.719	-	-
Na	8.871	3.807	7.430	-	-
H	6.645	-	-	-	-

TABLE VI. ZPR-9 Assembly 16, Loading 2, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	32.51
Driver	36.62
Reflector (depleted)	54.38
Reflector (steel)	86.05

Test-zone half height	45.72 cm
Axial depleted reflector thickness (each half)	12.70 cm
Axial steel reflector thickness (each half)	20.32 cm

Critical Mass, kg (^{235}U)

Test zone	115
Buffer	1
Driver	217
Total critical mass	333.1

	Atomic Concentrations, Units of 10^{21} atoms/cm^3				
Material	Test Zone	Buffer	Driver	Depleted Reflector	Steel Reflector
^{234}U	0.015	-	0.065	-	-
^{235}U	1.536	0.020	6.659	0.085	-
^{236}U	0.007	-	0.031	-	-
^{238}U	4.873	9.704	4.890	40.133	-
Fe	8.904	8.726	10.330	4.256	77.893
Cr	2.541	2.491	2.948	1.215	1.952
Ni	1.125	1.103	1.306	0.538	0.864
C	19.421	34.303	12.610	-	-
Na	8.871	3.807	7.369	-	-
H	6.645	-	-	-	-

TABLE VII. ZPR-9 Assembly 17, Loading 61, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	27.46
Reflector (depleted)	54.38
Reflector (steel)	86.02

Test-zone half height	45.72 cm
Axial depleted reflector thickness (each half)	12.70 cm
Axial steel reflector thickness (each half)	20.32 cm

Critical Mass, kg (^{235}U)

Test zone	126.9
Total critical mass	126.9

	Atomic Concentrations, Units of 10^{21} atoms/cm^3		
Material	Test Zone	Depleted Reflector	Steel Reflector
^{234}U	0.015	-	-
^{235}U	1.497	0.085	-
^{236}U	0.007	-	-
^{238}U	0.0857	40.133	-
Fe	8.854	4.256	77.893
Cr	2.527	1.215	1.952
Ni	1.119	0.538	0.864
C	27.491	-	-
Na	8.863	-	-
H	6.640	-	-

TABLE VIII. ZPR-9 Assembly 19, Loading 12, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	32.51
Driver	42.92
Reflector (steel)	56.48
Reflector (depleted)	77.35

Test-zone half height	45.72 cm
Axial steel reflector thickness (each half)	15.24 cm
Axial depleted reflector thickness (each half)	15.24 cm

Critical Mass, kg (^{235}U)

Test zone	87
Buffer	1
Driver	393
Total critical mass	481.2

	Atomic Concentrations, Units of 10^{21} atoms/cm^3				
Material	Core	Buffer	Driver	Steel Reflector	Depleted Reflector
^{234}U	0.011	-	0.044	-	-
^{235}U	1.156	0.017	4.471	-	0.085
^{236}U	0.005	-	0.021	-	-
^{238}U	5.789	8.242	0.255	-	40.133
Fe	14.360	6.839	28.328	77.893	4.256
Cr	2.979	1.952	8.083	1.952	1.215
Ni	1.319	0.864	3.579	0.864	0.538
C	-	-	29.761	-	-
Na	9.233	-	-	-	-
O	14.681	22.027	-	-	-
Al	-	18.738	-	-	-

TABLE IX. ZPR-9 Assembly 21, Loading 13, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	14.27
Buffer	20.89
Driver	32.59
Reflector (steel)	56.48
Reflector (depleted)	77.35

Test-zone half height	45.72 cm
Axial steel reflector thickness (each half)	15.24 cm
Axial depleted reflector thickness (each half)	15.24 cm

Critical Mass, kg (^{235}U)

Test zone	26
Buffer	1
Driver	311
Total critical mass	338.5

Atomic Concentrations, Units of 10^{21} atoms/cm^3

Material	Test Zone	Buffer	Driver	Steel Reflector	Depleted Reflector
^{234}U	0.011	-	0.043	-	-
^{235}U	1.152	0.017	4.443	-	0.085
^{236}U	0.005	-	0.021	-	-
^{238}U	5.770	8.232	0.254	-	40.133
Fe	14.335	6.839	28.129	77.893	4.256
Cr	2.959	1.952	8.027	1.952	1.215
Ni	1.310	0.864	3.554	0.864	0.538
C	-	-	29.605	-	-
Na	9.202	-	-	-	-
O	14.632	22.000	-	-	-
Al	-	18.718	0.065	-	-

TABLE X. ZPR-9 Assembly 22, Loading 10, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	32.51
Driver	42.12
Reflector (steel)	56.48
Reflector (depleted)	77.35

Test-zone half height	45.72 cm
Axial steel reflector thickness (each half)	15.24 cm
Axial depleted reflector thickness (each half)	15.24 cm

Critical Mass, kg (^{235}U)

Test zone	85
Buffer	0
Driver	359
Total critical mass	443.6

Atomic Concentrations, Units of 10^{21} atoms/cm^3

Material	Test Zone	Buffer	Driver	Steel Reflector	Depleted Reflector
^{234}U	0.011	-	0.044	-	-
^{235}U	1.129	-	4.462	-	0.085
^{236}U	0.005	-	0.021	-	-
^{238}U	5.654	-	0.255	-	40.133
Fe	14.128	6.839	28.325	77.893	4.256
Cr	2.930	1.952	8.082	1.952	1.215
Ni	1.298	0.864	3.579	0.864	0.538
C	-	-	29.604	-	-
Na	9.017	-	-	-	-
O	14.338	-	-	-	-
Al	-	50.759	-	-	-

TABLE XI. ZPR-9 Assembly 24, Loading 21, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	25.87
Buffer	30.67
Driver	51.41
Reflector (steel)	64.50
Reflector (depleted)	84.54

Test-zone half height	45.72 cm
Axial steel reflector thickness (each half)	15.24 cm
Axial depleted reflector thickness (each half)	15.24 cm

Critical Mass, kg (^{235}U)

Test zone	85
Buffer	1
Driver	416
Total critical mass	501.7

	Atomic Concentrations, Units of 10^{21} atoms/cm^3				
Material	Test Zone	Buffer	Driver	Steel Reflector	Depleted Reflector
^{234}U	0.011	-	0.021	-	-
^{235}U	1.135	0.0311	2.179	-	0.085
^{236}U	0.005	-	0.010	-	-
^{238}U	12.236	14.562	0.126	-	40.133
Fe	6.755	6.839	22.211	77.893	4.256
Cr	1.928	1.952	6.339	1.952	1.215
Ni	0.854	0.864	2.807	0.864	0.538
C	43.381	42.873	42.763	-	-

TABLE XII. ZPR-9 Assembly 25, Loading 24, As-built

Regional Cylindrical Equivalent Radii, cm

Test zone	18.94
Buffer	25.87
Driver	37.95
Reflector (stainless steel)	55.79
Reflector (depleted)	71.89

Test-zone half height	45.72 cm
Axial nickel reflector thickness (each half)	15.24 cm
Axial depleted reflector thickness (each half)	15.24 cm

Critical Mass, kg (^{235}U)

Test zone	86
Buffer	2
Driver	387
Total critical mass	475.3

	Atomic Concentrations, Units of 10^{21} atoms/cm^3					
Material	Core	Buffer	Driver	Radial SS Refl	Axial Nickel Refl	Depl Refl
^{234}U	0.020	-	0.044	-	-	-
^{235}U	2.140	0.073	4.474	-	-	0.085
^{236}U	0.010	-	0.021	-	-	-
^{238}U	33.233	33.959	0.255	-	-	40.133
Fe	6.839	6.839	12.907	56.474	6.839	4.256
Cr	1.952	1.952	3.684	16.115	1.952	1.215
Ni	0.864	0.864	1.631	7.136	75.423	0.538
C	-	-	51.218	-	-	-
Al	1.649	6.255	-	-	-	-

TABLE XIII. Measured Control-rod Worths

Assembly	Rod Numbers	% Δk/k	
		Dual-purpose, Fuel-bearing Control Rods	Boron Control Rods
11	1-10	0.23	0.23
12	4-7	0.28	0.10
	1-3, 8-10	0.25	
13	4-7	0.23	0.10
	1-3, 8-10	0.19	
14	4-7	0.25	-
	1-3, 8-10	0.19	
15	4-7		-
	1-3, 8-10		
16	4-7	0.26	-
	1-3, 8-10	0.18	
17	4, 5, 9, 10	0.19	-
	1-3, 7, 8	0.39	
19	4, 5, 9, 10	0.25	0.18
	1-3, 6-8	0.23	
21	4, 5, 9	0.37	-
	1-3, 6-8	0.35	
22	4, 5, 9	0.28	-
	1-3, 6-8, 10	0.24	
24	2, 4, 5, 6, 7, 9	0.14	0.36
	1, 3, 8, 10	0.33	
25	1-4, 6-9	0.24	-
	5, 10	0.29	

ACKNOWLEDGMENTS

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REFERENCES

1. R. A. Lewis, L. G. LeSage, and R. A. Karam, "ZPR-9 Assemblies 11 and 12--Two Small Zoned Versions of the 2600-Liter Assembly 5 ZPR-6" *Reactor Physics Division Annual Report: July 1, 1966 to June 30, 1967*, ANL-7310, pp. 190-196 (Jan 1968).

2. R. Pond and C. E. Till, "Doppler Effect Measurements in CH_2-Softened Spectra; ZPR-9 Assemblies 13-17," *Reactor Physics Division Annual Report: July 1, 1966 to June 30, 1967*, ANL-7310, pp. 159-163 (Jan 1968).

3. L. G. LeSage, E. F. Groh, and W. R. Robinson, "An Investigation of the Properties of Zoned Systems," *Reactor Physics Division Annual Report: July 1, 1967 to June 30, 1968*, ANL-7410, pp. 145-151 (Jan 1969).

4. L. G. LeSage and W. R. Robinson, "ZPR-9 Assemblies 19, 21, 22 and 24," *Reactor Physics Annual Report: July 1, 1967 to June 30, 1968*, ANL-7410, pp. 80-86 (Jan 1969).

5. C. E. Till, L. G. LeSage, G. S. Stanford, E. F. Groh, and W. R. Robinson, "Measurement of the Capture-to-Fission Ratio of U-235 and Pu-239 in the Kilovolt Region Using Critical Assembly Null-Reactivity Techniques," *Reactor Physics Division Annual Report: July 1, 1967 to June 30, 1968*, ANL-7410, pp. 169-171 (Jan 1969).

6. L. G. LeSage, "Zoned Critical Experiments," *Reactor Development Program Progress Report: August 1969*, ANL-7606, pp. 17-19.

7. L. G. LeSage and W. R. Robinson, "ZPR-9 Assembly 25; Description and Experimental Results," *Applied Physics Division Annual Report: July 1, 1969 to June 30, 1970*, ANL-7710 (Jan 1971).